Simultaneous Contact Assessment CASCADE

Revision 1.1

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Contents

Introduction

Purpose

The purpose of this document is to describe:

- Protective Multiple Earthing (PME) arrangement;
- the fault conditions which can arise as a result of a broken or open Protective Earth and Neutral conductor;
- the simultaneous contact implications for Electric Vehicle (EV) charging;
- Protective Earth Neutral (PEN) fault mitigation and the implications for **Trojan HOME**.

Scope

This document is limited in scope to the deployment of the Trojan Energy Limited domestically connected, cross pavement EV charging solution, **Trojan HOME** (see https://trojan.energy/trojanhome).
Trojan HOME consists of a wall box assembly, fed from the domestic consumer unit in a manner consistent with typical at home charging solutions. The design differs in that the wall box feeds the Trojan Energy Limited proprietary cross pavement charging solution which sits flat and flush to the walkway, immediately adjacent to the public highway.
Trojan HOME integrates control, safety and communications electronics. Safety functions include:

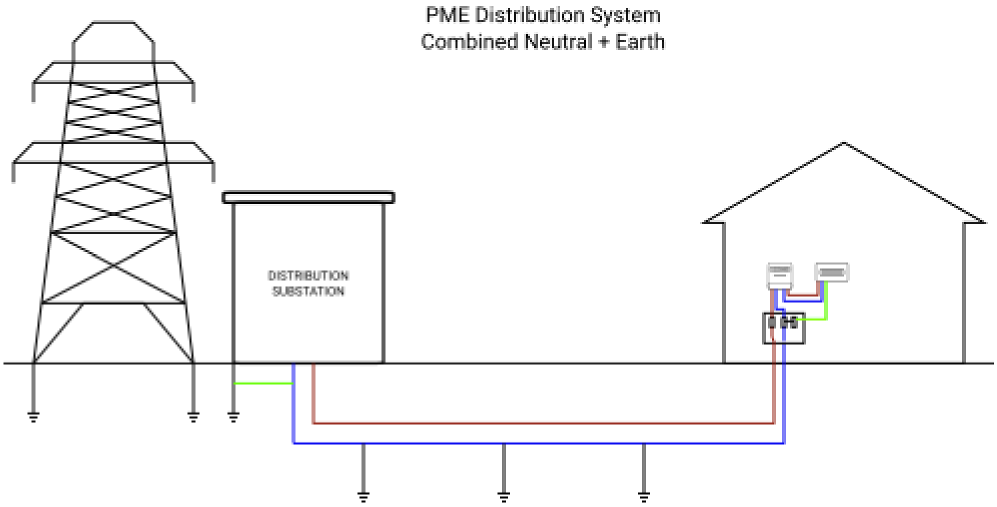
- Residual Current Protection
- Protective Earth Continuity Protection
- Overcurrent Protection
- Open Protective Earth Neutral Protection
- Diverted Neutral Current Protection

Sources

This document summarises the Trojan Energy Limited analysis of electrical risks, the safest approach to mitigate risk and is derived from various sources of information made available from the IET (see References).

1. PME Supply

Let us first look at what a PME supply is and the function of a PEN conductor in a TN-C-S arrangement. The Earth and neutral are combined in the same conductor from the distribution transformer up to the consumer installation. Once the electrical supply is terminated into the service head the PEN conductor is split into two terminals, one is neutral the other is Earth. This is the most common earthing arrangement in the UK it is also called Protective Multiple Earth because it could have more than one source of Earth electrode along the length of the buried supply cable.



2. Open PEN Fault

In the event of the distributor's PEN conductor becoming broken (open-circuit), diverted neutral currents and dangerous touch voltages can appear on any metalwork connected to the Main Earthing Terminal (MET) of the installation.

The risk of electric shock is increased for persons outdoors, as they are likely to be in simultaneous contact with Earth, possibly even barefooted, which would lower the body resistance to Earth and increase the touch current.

Common examples of risk would include outside water taps and Class I electrical equipment connected to the MET [1] and Electric Vehicles (EVs). Fire can also be a risk due to the heating effect of extraneous-conductive-parts, such as water and gas pipes caused by the diverted neutral current. The risk for a **Trojan HOME** installation is most likely to be from street lighting fixtures, or other EVs charging in the vicinity.

Under open-circuit PEN conditions, the voltage between the neutral and Earth will depend on the ratio of the balance of load on the distribution network. In some cases, this can be up to 230 V. This becomes more complex when power factor is taken into consideration. In a three-phase distribution system the common neutral connection is the star point.

If the load is not balanced, a current will flow in the neutral conductor, this will be a phasor sum of the line currents. If the PEN conductor becomes open-circuit, the neutral current cannot flow. The voltages between line and neutral 'shift' until a balance point is reached eliminating the need for a neutral current. The star point is said to 'float' to a position that achieves balance.

This is illustrated using the phasor diagram of Figure 1. The distance from the centre point of the triangle to the displaced star point of the three-phases indicates the touch voltage to Earth; 64 V. The star point has moved towards the heaviest loaded phase, in this case, L3.

[1] Class I electrical equipment is a type of electrical appliance that uses a built-in earth wire and basic insulation to ensure safety

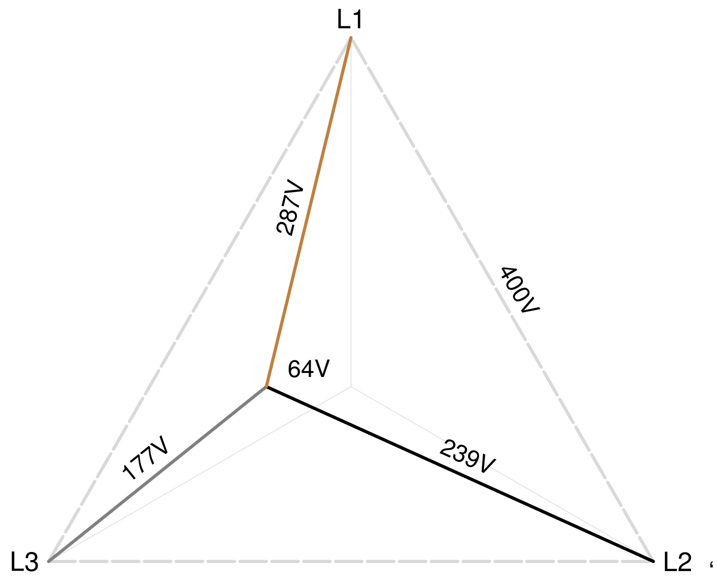


Figure 1. Unbalanced Three Phase System Touch Voltage [2]

This condition will cause an overvoltage in some phases and undervoltage in others and is likely to cause equipment not designed to operate at either condition to malfunction or be damaged. It is a dynamic situation as when equipment installed on the affected phase malfunctions, this also affects the load demand and balance of the network and thus the voltage to Earth also changes.

Regulation 442.3 of [BS 7671] provides information regarding the power frequency stress voltage, in the event of loss of the neutral conductor in a TN or TT system.

2.1 Three-phase Balanced Network

In a three-phase balanced network there is no neutral current (where there are no triple harmonics). However, it should be remembered that any electrical installation comprising several single-phase loads is unlikely to be or remain balanced for a period of time.

It should also be remembered that the voltage to Earth will depend on the ratio of balance on the distribution network and not just the consumer's installation.

2.2 Scenario 1 Normal Operating Conditions

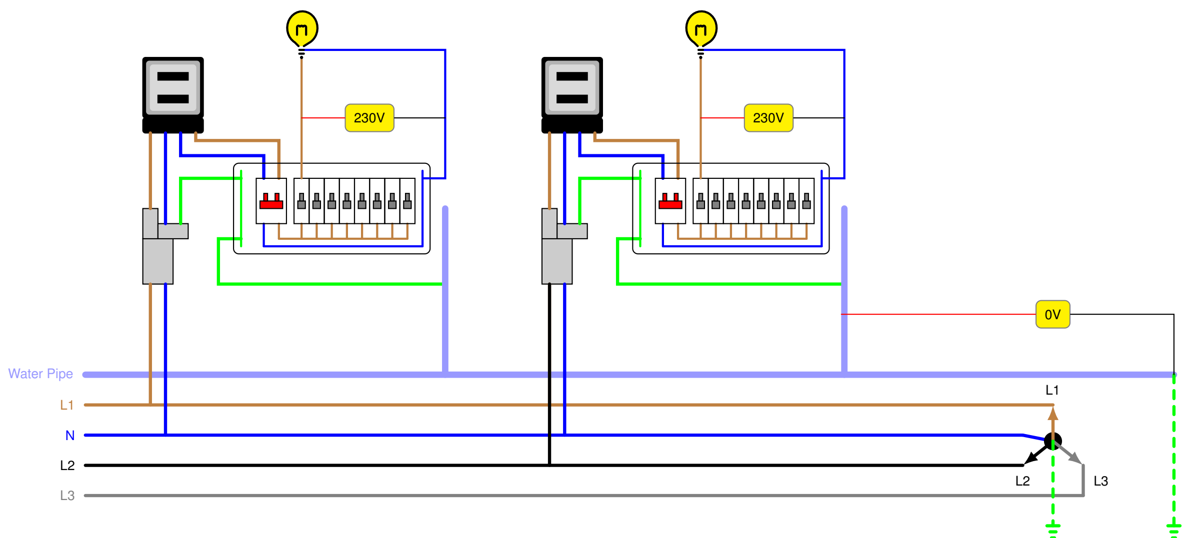


Figure 2. Normal Operating Conditions [3]

[2] Derived from Wiring Matters

Under normal operating conditions, the current path returns from each property via the PEN conductor to the distribution transformer; in such conditions there is no voltage between PME neutral and Earth.

Under this scenario a **Trojan HOME** charging station would operate as intended. The Open PEN protection in the **Trojan HOME** device would remain closed.

2.3 Scenario 2A : Open-circuit PEN Conductor in Single-Phase Section of Cable - Domestic

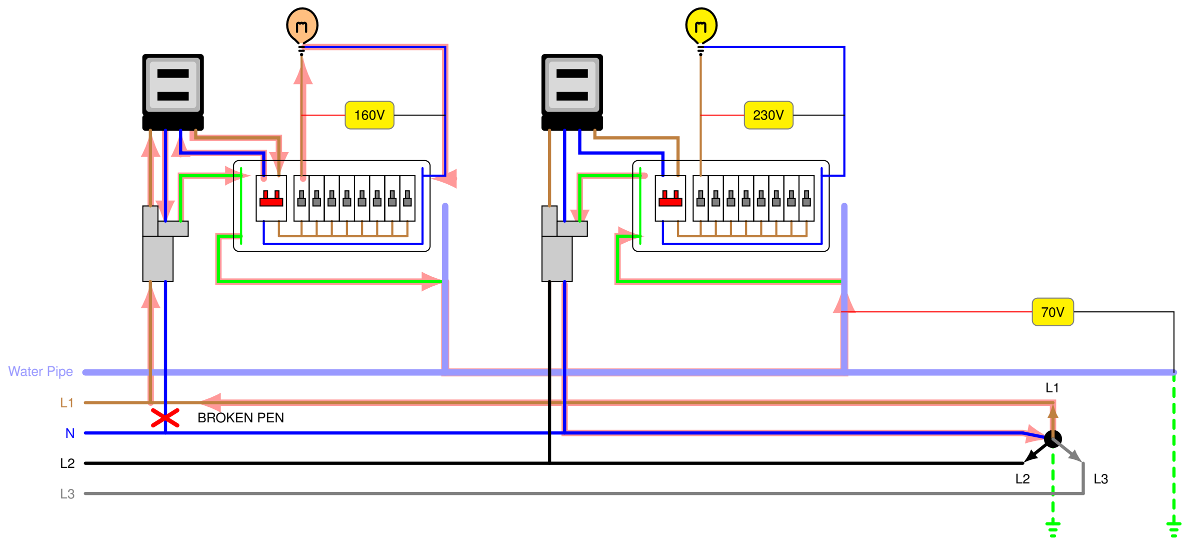


Figure 3. Single Phase Open PEN [4]

In the event of an open-circuit PEN conductor on the single-phase section of cable, the return path is via the extraneous-conductive-part, such as a metallic water pipe shared with an adjacent installation. This will cause a touch voltage between any connected exposed and extraneous-conductive-parts to Earth, the voltage will vary according to the resistance of the return path. Property 1 on phase L1 has an exported diverted neutral current via the extraneous metallic water pipe. Property 2 on phase L2 has an imported diverted neutral current via the extraneous metallic water pipe. A shock potential exists for anyone accessing the shared metallic water pipe if they provide a suitable path to ground.

If connected to Property 1 on phase L1 under this scenario a **Trojan HOME** charging station would be isolated. The Open PEN protection in the **Trojan HOME** device would detect the undervoltage caused by the broken PEN fault and isolate the charge station. If connected to property 2 on phase L2 under this scenario a **Trojan HOME** charge unit would not pre-emptively detect the open PEN fault and the supply to the charge station would remain closed, causing a touch voltage shock potential if a person provides a suitable path to ground. A shock event would however be detected and the consequence mitigated by the rapid response of the **Trojan HOME** safety electronics (either residual current protection or diverted neutral current protection).

[3] Derived from Wiring Matters
[4] Derived from Wiring Matters

2.4 Scenario 2B : Open-circuit PEN Conductor in Single-Phase Section of Cable - Cross Pavement

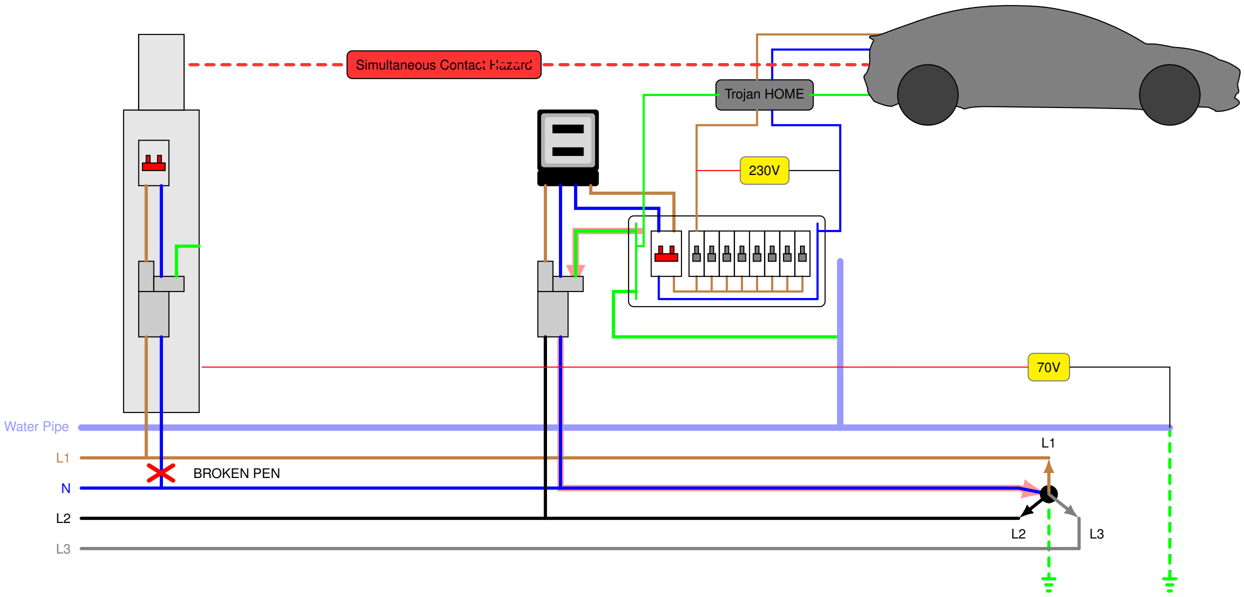


Figure 4. Single Phase Open PEN : Street Lighting [5]

In the event of an open-circuit PEN conductor on the single-phase section of cable into a street light fitting, the return path will be via the exterior metallic parts of the fitting to ground. The touch voltage would be dependent on the impedance of that path to ground which means it could be up to 230V.

An adjcent charging EV will present a low impedance, and therefore potentially preferential, path to ground. Any person in contact with the metallic exterior of the EV and the light fitting could be subject to an electric shock. Under this scenario a **Trojan HOME** charging station would detect the diverted neutral current flowing in the Protective Earth conductor and the Open PEN protection in the **Trojan HOME** device would rapidly disconnect the live and Protective Earth conductors to mitigate the consequence of a shock event.

2.5 Scenario 3 Open-circuit PEN Conductor in Three-Phase Section of Cable

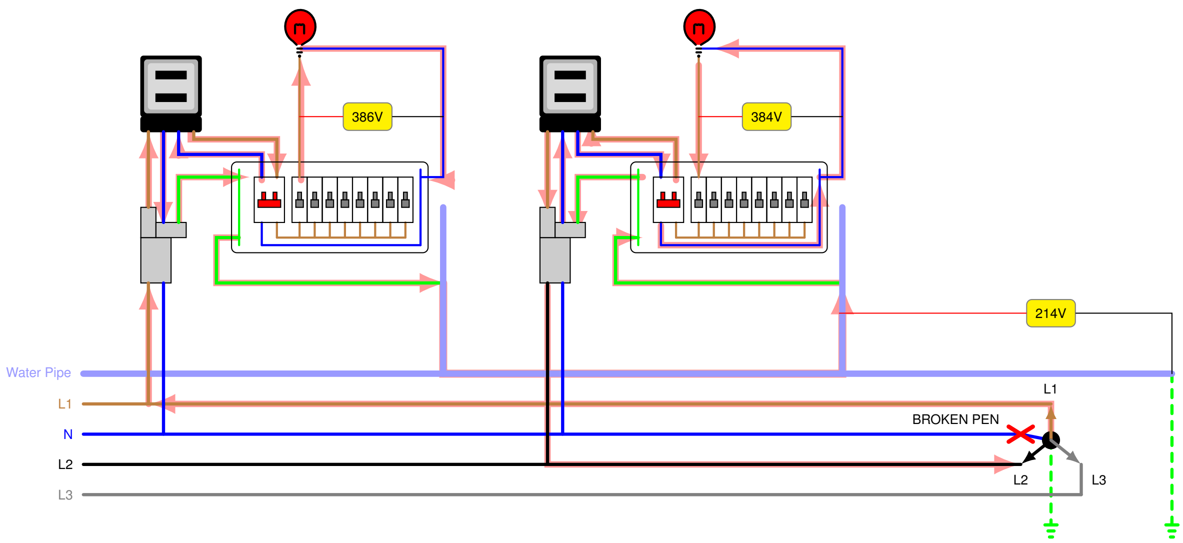


Figure 5. Three Phase Open PEN [6]

If the PEN conductor breaks in a section of three-phase cable, the return path will be via the adjacent installation, back to the L2 phase. This means that up to 400V could exist within the single-phase installation. The voltage to Earth will

[5] Derived from Wiring Matters
[6] Derived from Wiring Matters

be higher if the distribution network is unbalanced.

In the real world, the situation is likely to be much more complex with many variables affecting the level of touch voltage and diverted neutral current. It is possible that the combined neutral currents for several installations could return via one installation. This situation, which can be difficult to detect, results in a voltage to Earth of up to 230V and a voltage between live conductors up to 400V present at any point in those installations that are affected by the break in the neutral conductor.

Under this scenario a **Trojan HOME** charging station would be isolated if connected to either property 1 on phase L1 or property 2 on phase L2. The Open PEN protection in the **Trojan HOME** device would detect the over voltage caused by the broken PEN fault and isolate the charging station pre-emptively.

3. TT Earthing Mitigation

If the risk of an open-circuit PEN conductor is not acceptable, TT Earthing arrangements are a reliable and effective method. An earth electrode can be installed to create a TT earthing arrangement, either for part of or for the whole installation. [BS 7671] generally requires a resistance value of less than 200 ohms, with RCDs installed to provide fault protection. However, installing a TT earthing arrangement does not come without risk, care should be taken to avoid striking buried underground services, such as cables and pipes. Service location drawings will be required to determine the location of existing underground services.

It is also important to ensure requirements are adhered to with respect to minimum separation distance from other earthing systems or buried conductive parts connected to other earthing systems. This is to prevent voltages appearing on the TT earthing arrangement in the event of an open-circuit PEN conductor fault. DNOs have their own requirements, so it is important to check.

Further information can be found in the code of practice for protective earthing of electrical installations [BS 7430].

For each charge station installation a risk assessment must first be carried out to identify if any simultaneous contact risks exist, e.g. between a lighting column and a vehicle under charge. For installations where a simultaneous contact risk exists between a vehicle and a lighting column, the lighting column would need to be changed to a TT earth and the supply to the lighting column should also be changed to be on the same phase as the supply to the charge station.

Whilst TT earthing arrangements provide a suitable way of mitigating the risks with an open PEN fault, the efficacy is not guaranteed and the costs may be prohibitively high and therefore commercially unviable for cross pavement installations.

4. Open PEN Mitigation

Open PEN Detection Devices monitor the mains supply parameters and are capable of detecting Open PEN fault conditions. Under fault conditions the output of the Open PEN device is used as a control to open a contactor supplying an affected circuit, such as the supply to an EV charge station. Disconnecting all conductors to the circuit (Line, Neutral and Protective Earth) eliminates the simultaneous contact risk introduced by the Open PEN fault.

Recently the IET published a standard outlining the requirements for open combined protective and neutral conductor detection devices (OPDDs). It should be noted the [IET 01] publication is not a designated standard, however no consolidated standard approach or specification for how EV equipment should operate in case of an open PEN fault exists. It is anticipated this standard will eventually become a requirement for OPDD devices installed in installations adhering to the BS7671 wiring regulations.

The methods of operation for open pen combined protective and neutral conductor detection devices (OPDDs) are detailed in [IET 01] are as follows:

Method M1a: Supply Voltage Range

When the voltage between line and neutral conductors exceeds 262.2 V AC When the voltage between line and neutral conductors does not exceed 207 V AC

Method M1b: Increased Supply Voltage Range

When the voltage between line and neutral conductors exceeds 262.2 V AC When the voltage between line and neutral conductors does not exceed 184 V AC Method M1b shall only be used in conjunction with method M3

Method M2a: Earth Electrode to Protective Earth or Neutral Voltage

When the voltage of the PEN conductor between and a measurement earth electrode exceeds 70 V AC

Method M2b: Other Means of Detection of Rise of PEN Conductor Potential

For a device suitable for use in a three-phase system only, when the device detects that potential of the PEN conductor with respect to Earth exceeds 70 V AC

Method M3: Protective Conductor Current

When the protective conductor current is 21 mA or more. Method M3 shall not be used as the sole method of operation

Methods M1a and M1b both measure the voltage between line and neutral. The possible touch-voltages depend on whether the distribution main is three-phase or single phase.

Method of operation M1a does not align with the voltage threshold in ENA engineering recommendations [G98] and [G99], and therefore an OPDD with method of operation M1a is considered generally incompatible with vehicle-to-home and vehicle-to-grid applications. As Trojan Energy is actively developing **Trojan HOME** products to be compliant to vehicle-to-home and vehicle-to-grid applications this discounts the method of operation M1a.

Method M2a (single phase) requires the installation of an additional earth electrode. Installation of an additional earth electrode is not without it's own technical risk and would increase installation costs and would therefore make any cross pavement system installation less commercially viable.

The risk of non-operation of an OPDD with method of operation M1b with a touch voltage exceeding 70 V is not tolerable, especially considering the increased likelihood that OPDDs on two phases at once will fail to operate. The [IET 01] standard therefore requires that Method 1b must also have additional protection by Method M3.

The **Trojan HOME** product roadmap and the guidance detailed in the [IET 01] standard, effectively determines that Method M1b in conjunction with Method M3 is the optimal practical solution for **Trojan HOME** Open PEN Detection

5. Trojan HOME Open PEN Detection

Trojan HOME incorporates Open PEN Detection utilising Method 1b in conjunction with Method 3. Additionally, **Trojan HOME** installations are installed in accordance with the BS7671 wiring regulations and additional risk assessments are conducted in accordance with the appropriate EV charging code of practice [COP 01]

The control electronics include integrated 3-phase metering via current transformers and measures line to neutral and line to line voltages. The control electronics can also be configured for single phase operation, where Line 1 is connected to L1, Neutral to N and Protective Earth connected to L3. When used in single phase configuration it shall be possible to monitor the Protective Earth for diverted Neutral current via a current transformer. Most domestic installations will have some level of earth leakage current, typically this shall be in the milliampere (mA) range. Under diverted Neutral conditions it is probable the diverted neutral current will be in the ampere (A) range. By monitoring both line to neutral voltages and Protective Earth current the likelihood of detecting an Open PEN condition is maximised but the requirement remains to trip at the 21mA threshold. If thresholds for voltage / current are exceeded the control electronics would automatically disconnect the circuit to the vehicle under charge in conformance with the maximum break times specified in [IET 01] for methods of operation M1b and Method 3, eliminating the possibility of a simultaneous contact event involving a vehicle connected to a **Trojan HOME** charge point.

6. Conclusion

For EV charger installations at customer properties fed via a TN-C-S (protective multiple earth) supply, Trojan Energy Limited shall supply the **Trojan HOME** equipment via a separate distribution board equipped with Method 1b and Method 3 OPDD to mitigate simultaneous contact risks associated with neutral fault conditions which may arise on the supplier distribution network. In addition, Trojan Energy Limited shall progress further development of the control electronics and aim to implement, test and verify Method 1b and Method 3 OPDD functionality integral to the **Trojan HOME** EV charger to mitigate against simultaneous contact risk.

7. Terms & Abbreviations

AC	Alternating Current
DNO	Distribution Network Operator
ENA	Energy Networks Association
EV	Electric Vehicle
IET	Institute of Engineering and Technology
MET	Main Earthing Terminal
OPDD	Open combined protective and neutral (PEN) conductor detection device
PEM	Protective Earth Monitor
PE(N)	Protective Earth (Neutral)
PME	Protective Multiple Earth
RCBO	Residual Current Breaker with Overcurrent
RCD	Residual Current Device
TN-C-S	Terra Network - Combined - Separate
TT	Terra Terra - Earthing system with dedicated earth electrode at the customers installation

Trojan HOME Trojan Energy Limited consumer connected cross pavement EV charging solution

8. References

[IET01] IET *IET 01:2024, Open combined protective and neutral (PEN) conductor detection devices (OPDDS)*

[COP01] IET *IET Code of Practice for Electric Vehicle Charging Equipment Installation*

[BS7671] IET *BS 7671:2018+A2:2022+A3:2024, Requirements for Electrical Installations*

[BS7430] BSI *BS 7430:2011+A1:2015, Code of Practice for Protective Earthing of Electrical Installations*

[Wiring Matters] IET *https://electrical.theiet.org/wiring-matters/years/2021/84-march-2021/broken-pen*

[G98] ENA *Engineering Recommendation G98, Issue 1, Amendment 7, 3 October 2022,Requirements for the connection of Fully Type Tested Micro-generators (up to and including 16 A per phase) in parallel with public Low Voltage Distribution Networks on or after 27 April 2019*

[G99] ENA *Engineering Recommendation G99, Issue 1, Amendment 9, 3 October 2022, Requirements for the connection of generation equipment in parallel with public distribution networks on or after 27 April 2019*